Measurement and Simulation of Vector Hysteresis Characteristics

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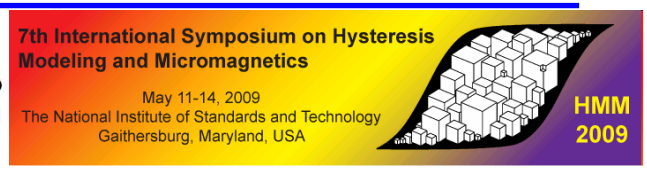
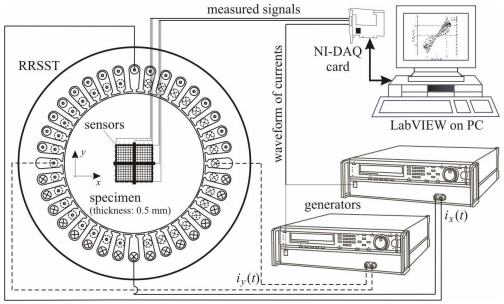
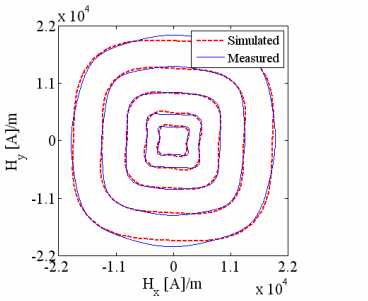


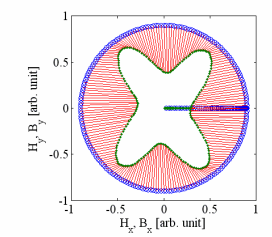
Outline

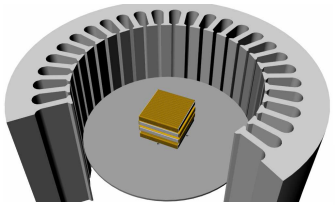
- Rotational Single Sheet Tester
  - Arrangement
  - Sensors
  - Results



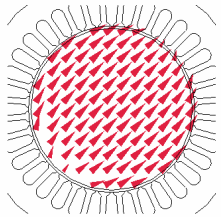


- Vector Preisach model
  - Model description
  - Identification
  - Comparisons





- Application in Finite Element Method
  - Fixed point method
  - Results



- Conclusions

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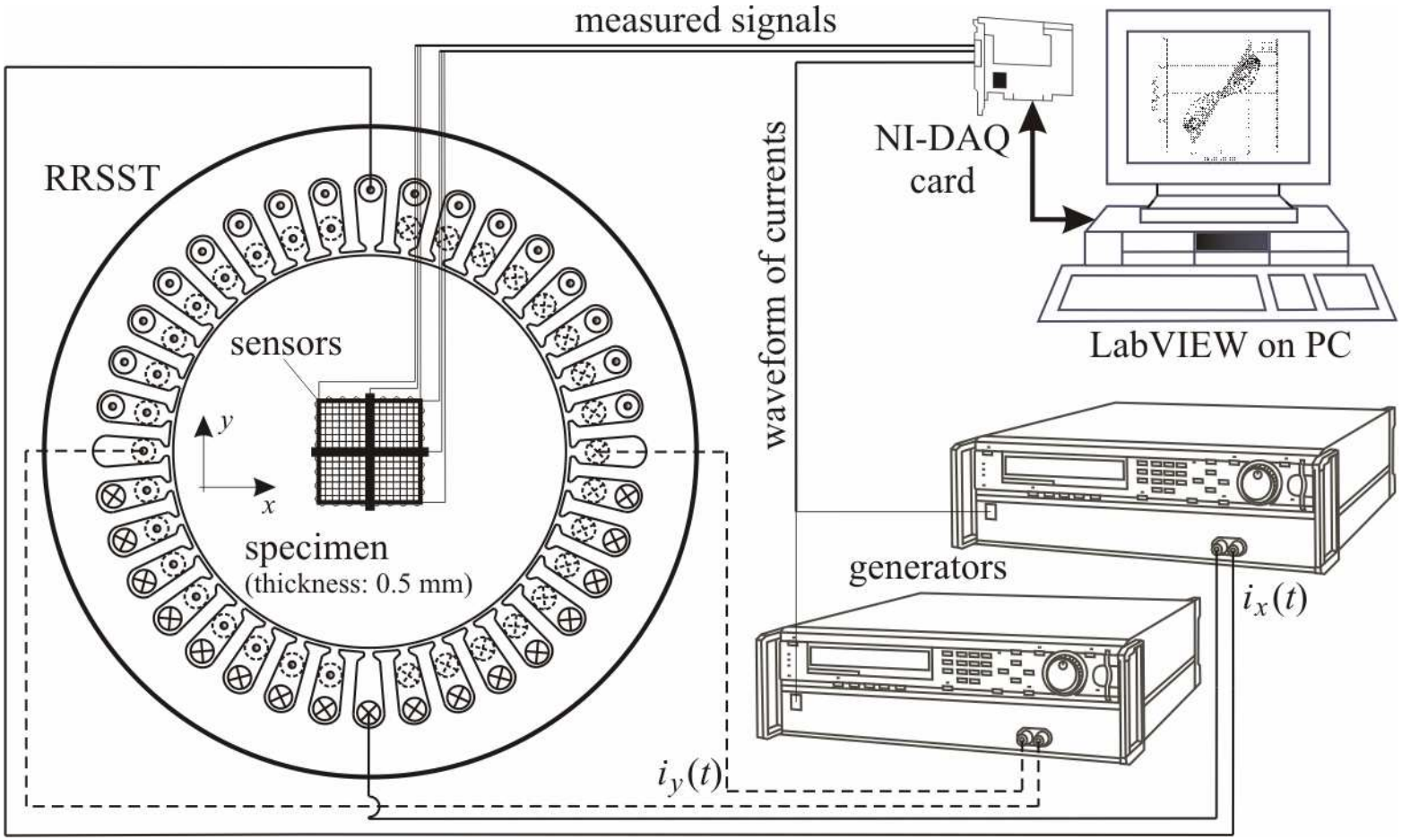
Block Diagram of the RRSST System

RRSST – **R**ound shaped **R**otational **S**ingle **S**heet **T**ester



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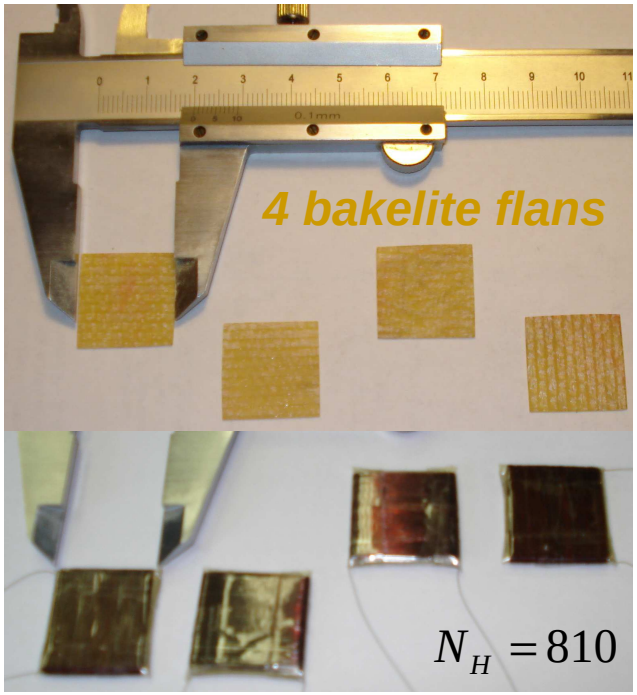
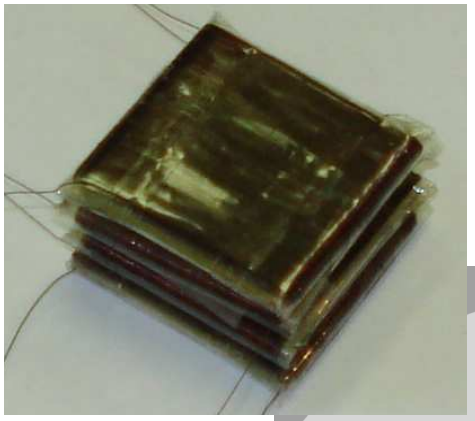
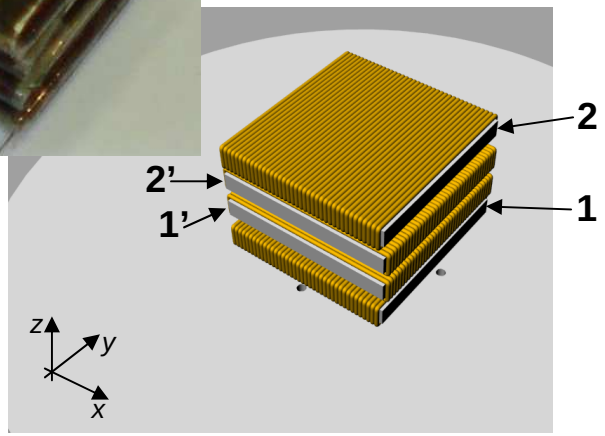
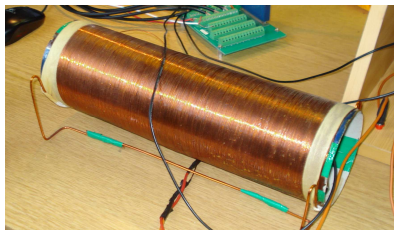
Construction of H-sensors







$$H(t) = H_0 + \frac{1}{\mu_0 S_H N_H} \int_0^t u(\tau)\,\mathrm{d}\tau$$



Linear extrapolation

$$H(z=0) = \frac{d_2 H_1 - d_1 H_2}{d_2 - d_1}$$

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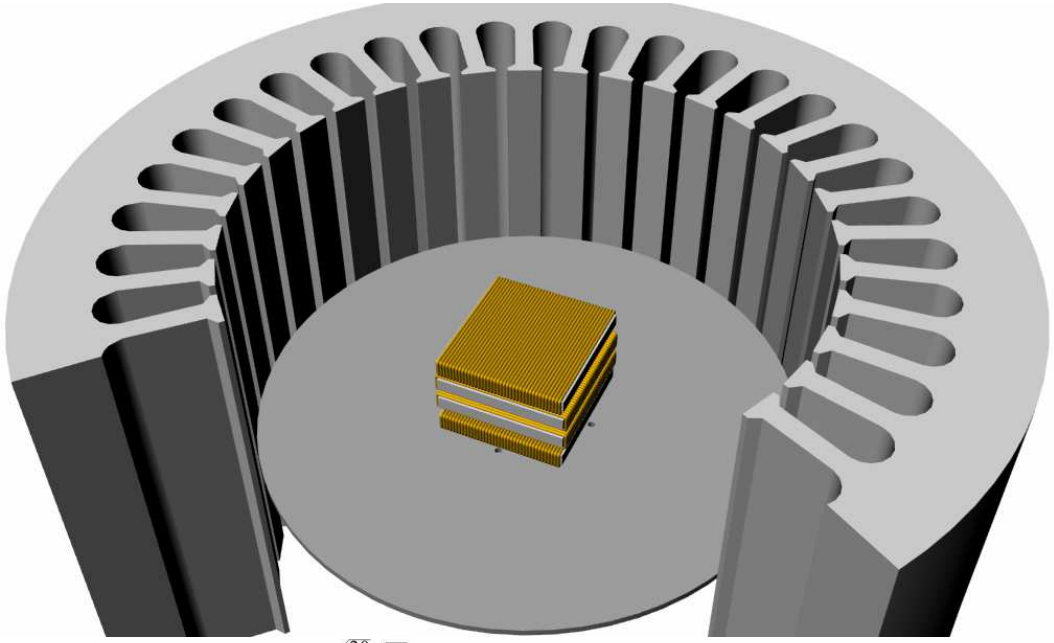
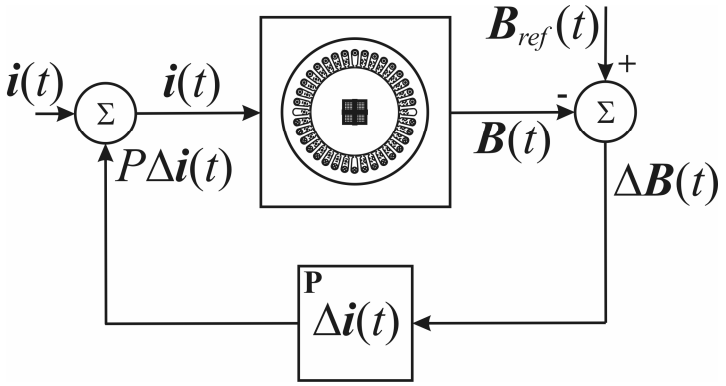
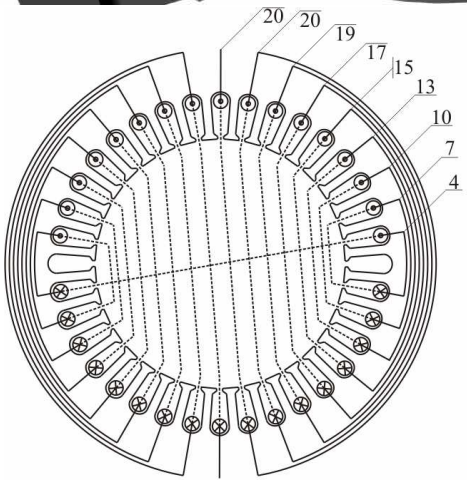
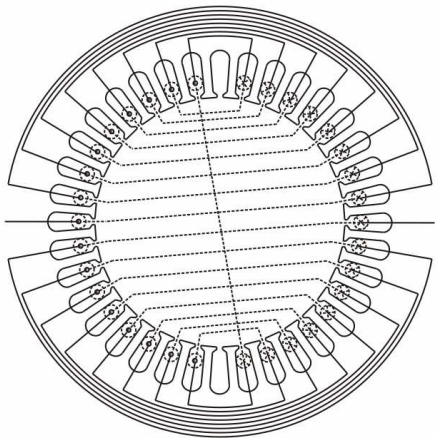
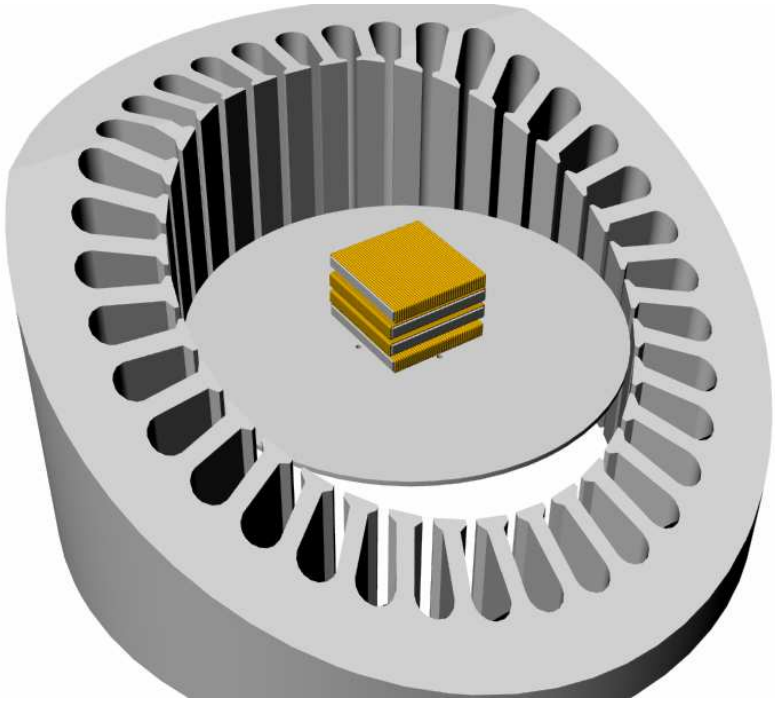
The RRSST System











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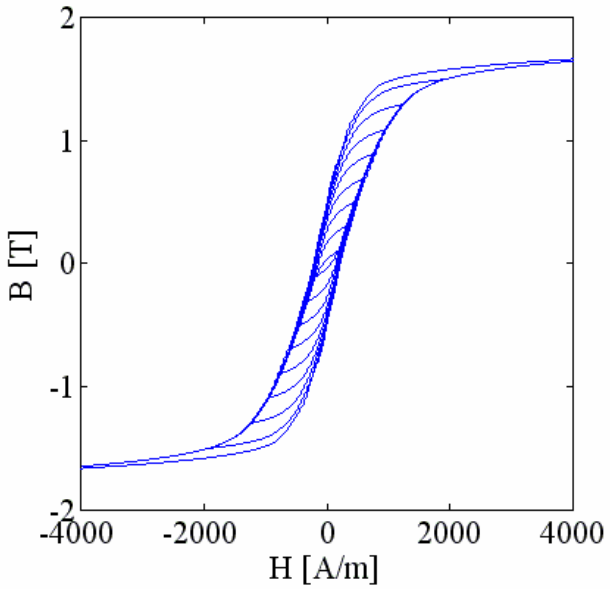
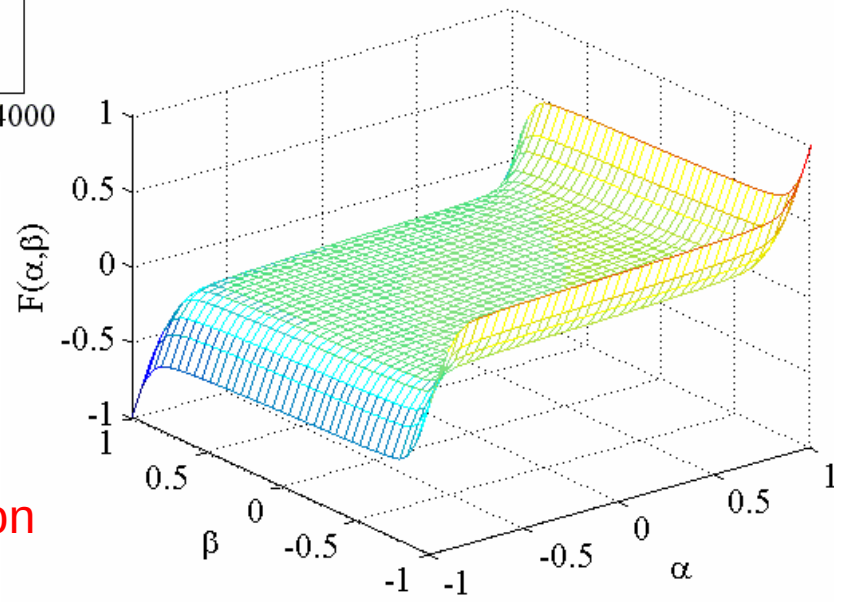
Measured Results

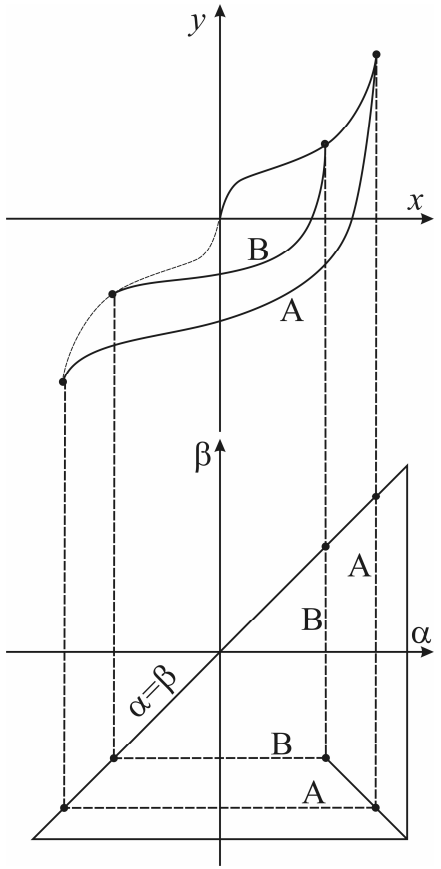


$$F(\alpha,\beta)=\frac{1}{2}\left(H_{\alpha}-H_{\alpha\beta}\right)$$

Everett function from concentric minor loops



2D spline approximation



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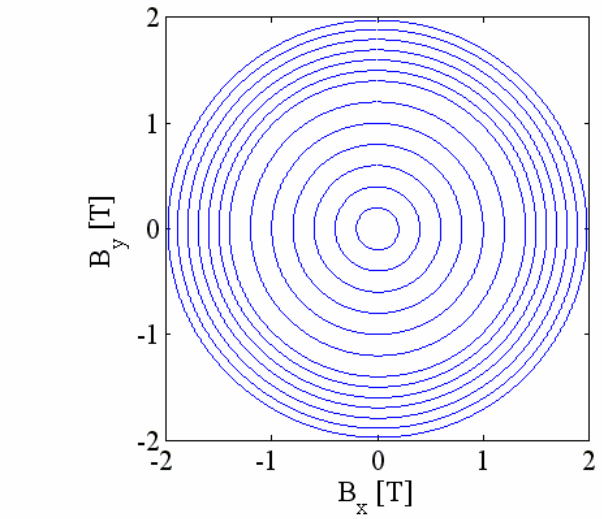

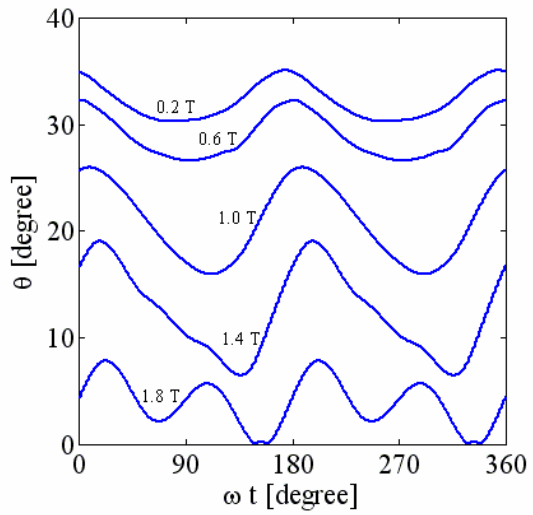

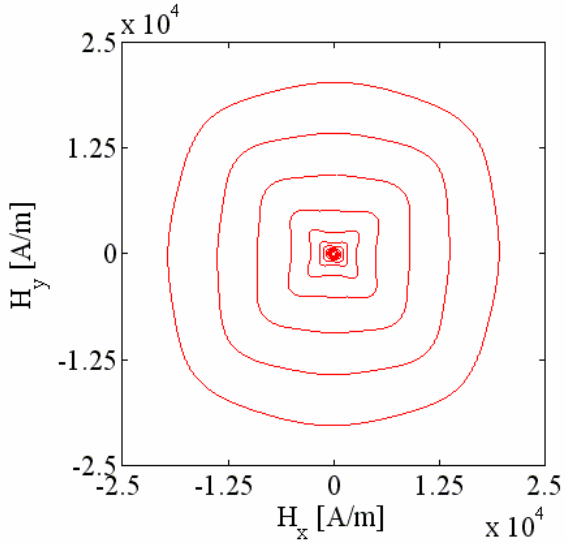

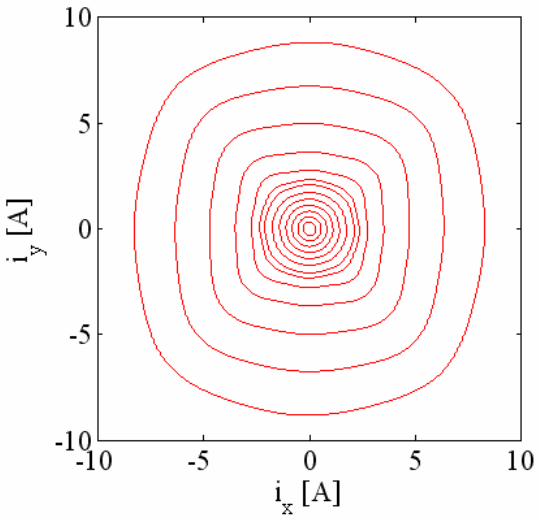

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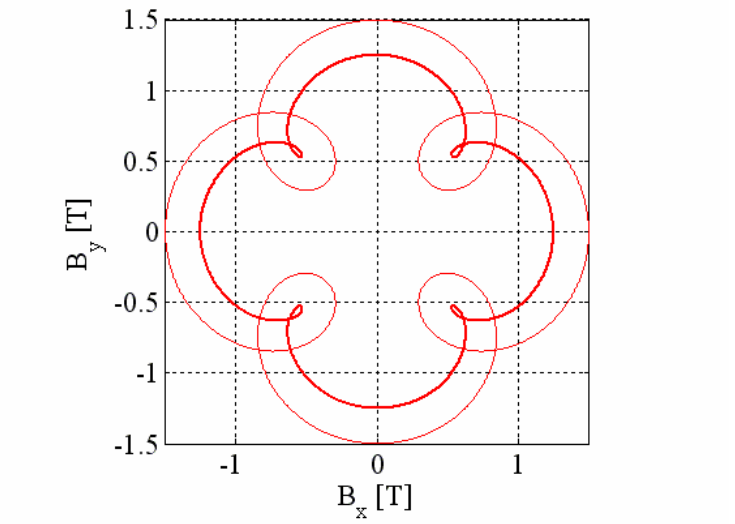

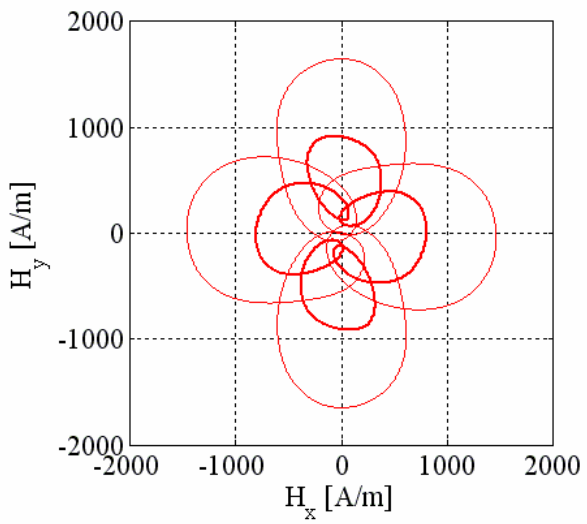

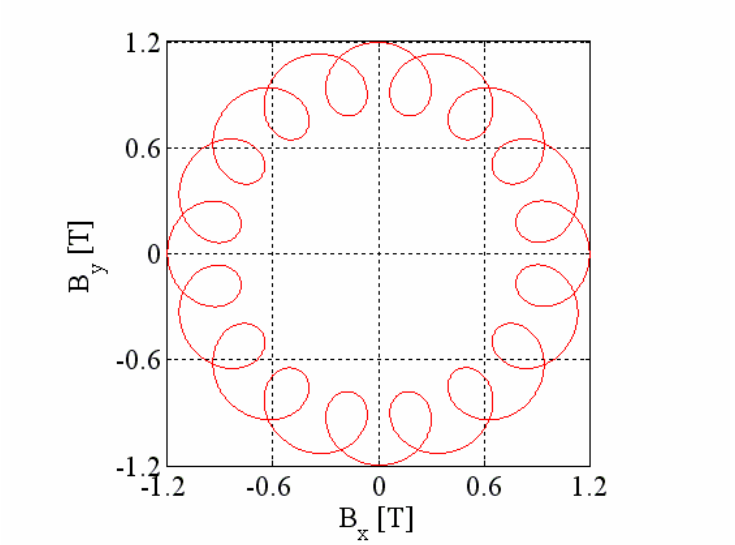

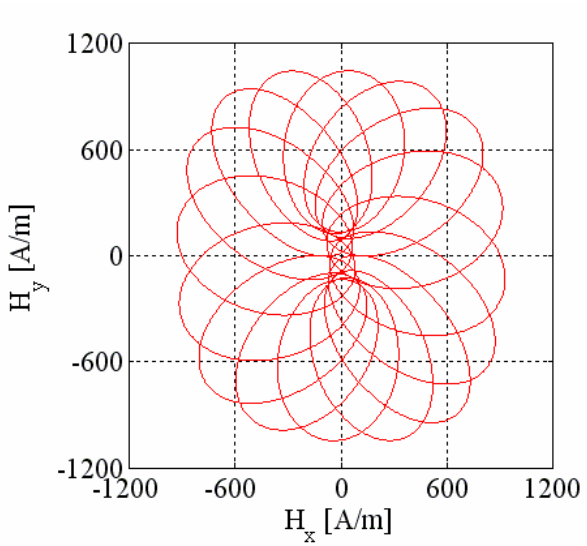

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Inverse Vector Preisach Model

$$\boldsymbol{H}(t)=\int_{-\pi/2}^{\pi/2}\boldsymbol{e}_{\varphi}\,\mathcal{B}\{B_{\varphi}\}\mathrm{d}\varphi \quad\Rightarrow\quad \boldsymbol{H}(t)\cong\sum_{i=1}^{n}\boldsymbol{e}_{\varphi_i}\,\mathcal{B}\{B_{\varphi_i}\}\Delta\varphi$$

$$\boldsymbol{B}=B_x\boldsymbol{e}_x+B_y\boldsymbol{e}_y$$

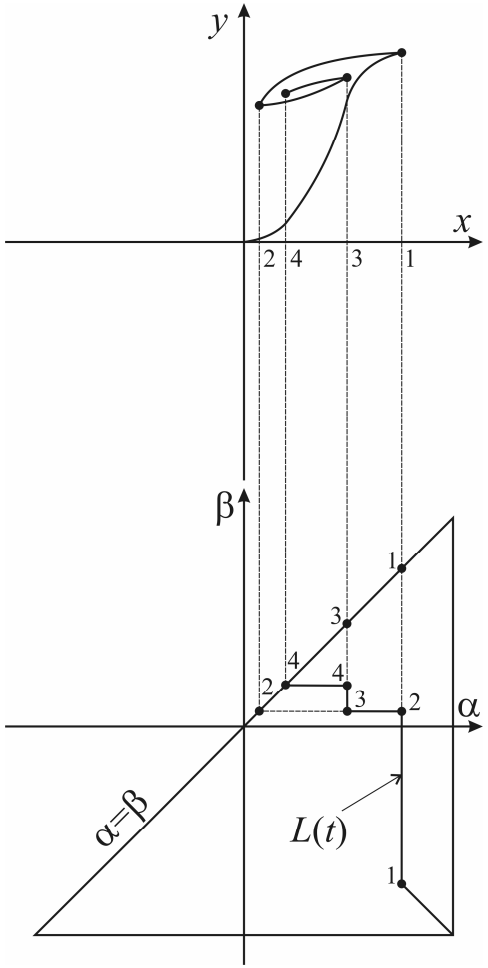
$$B_{\varphi_i}=B_x\cos\varphi_i+B_y\sin\varphi_i$$

$$B_{\varphi_i}=B_x\,\mathrm{sign}(\cos\varphi_i)\left|\cos\varphi_i\right|^{1/w}+B_y\,\mathrm{sign}(\sin\varphi_i)\left|\sin\varphi_i\right|^{1/w}$$

$$H_x=\sum_{i=1}^{n}H_{\varphi_i}\cos\varphi_i$$

$$H_y=\sum_{i=1}^{n}H_{\varphi_i}\sin\varphi_i$$

$$\boldsymbol{H}=H_x\boldsymbol{e}_x+H_y\boldsymbol{e}_y$$



$$B_{\varphi_i}=B_x\,\mathrm{sign}(\cos[\varphi_i+\psi])\left|\cos[\varphi_i+\psi]\right|^{1/w}+B_y\,\mathrm{sign}(\sin[\varphi_i+\psi])\left|\sin[\varphi_i+\psi]\right|^{1/w}$$

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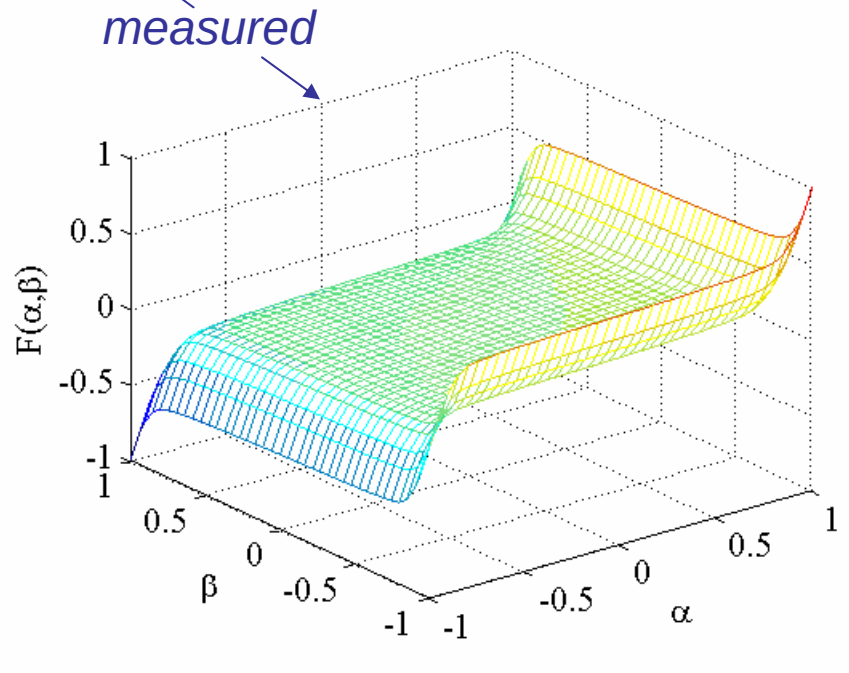
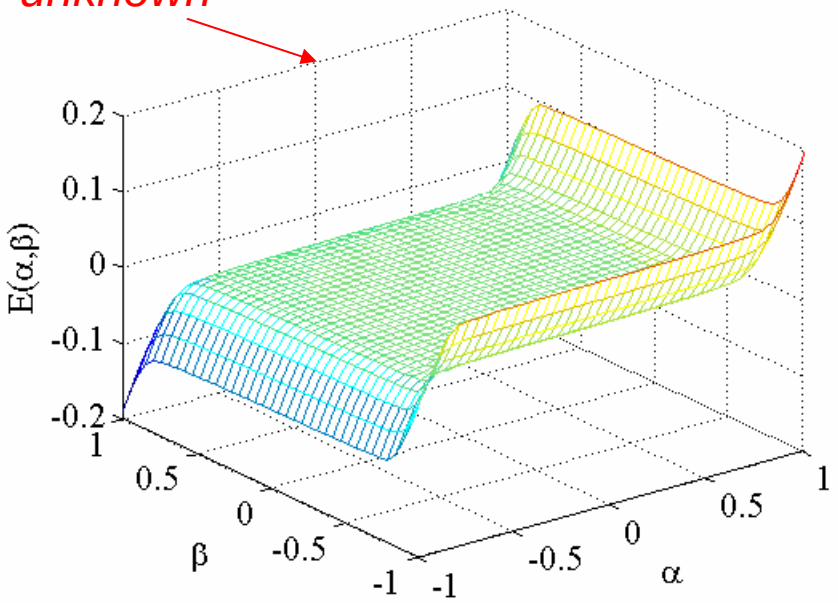
Inverse Vector Preisach Model

$$F(\alpha,\beta) = \int_{-\pi/2}^{\pi/2} \cos\varphi \, E\left(\alpha\cos^{1/w}\varphi, \beta\cos^{1/w}\varphi\right) \mathrm{d}\varphi \cong \sum_{i=1}^{n} \cos\varphi_i \, E\left(\alpha\cos^{1/w}\varphi_i, \beta\cos^{1/w}\varphi_i\right)\Delta\varphi$$

measured



unknown



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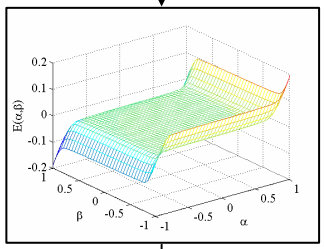
Inverse Vector Preisach Model

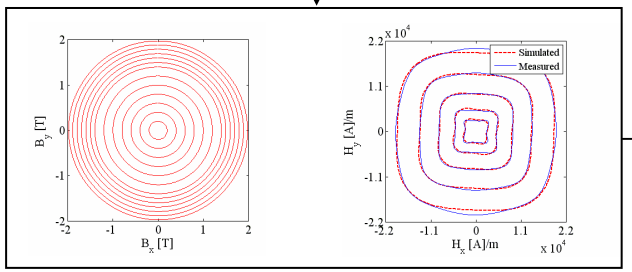
Initialization
n=14, w=1, ψ=0°

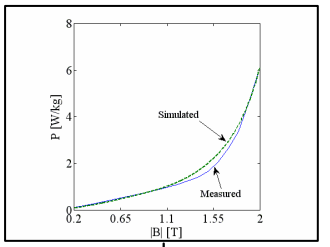
Result:
n=14, w=1.0894, ψ=1.3°

Vector Everett function

$$F(\alpha,\beta)=\int_{-\pi/2}^{\pi/2}\cos\varphi\,E\left(\alpha\cos^{1/w}\varphi,\beta\cos^{1/w}\varphi\right)\mathrm{d}\varphi$$







ψ

Error

n

y

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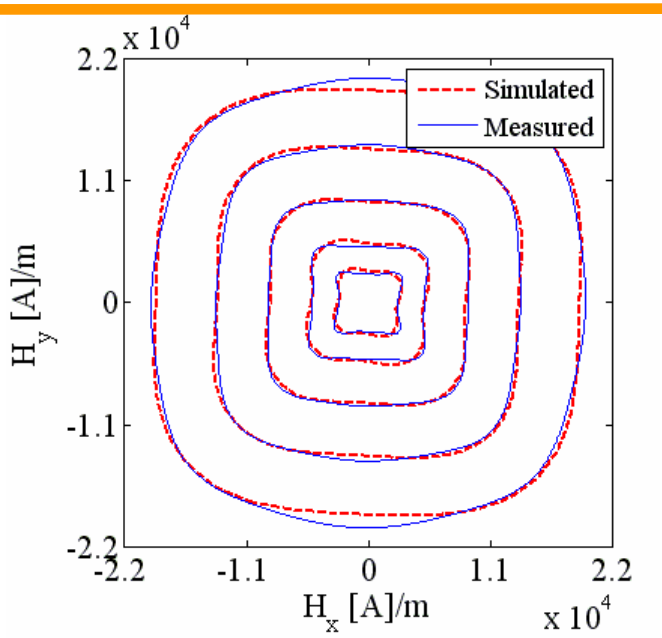

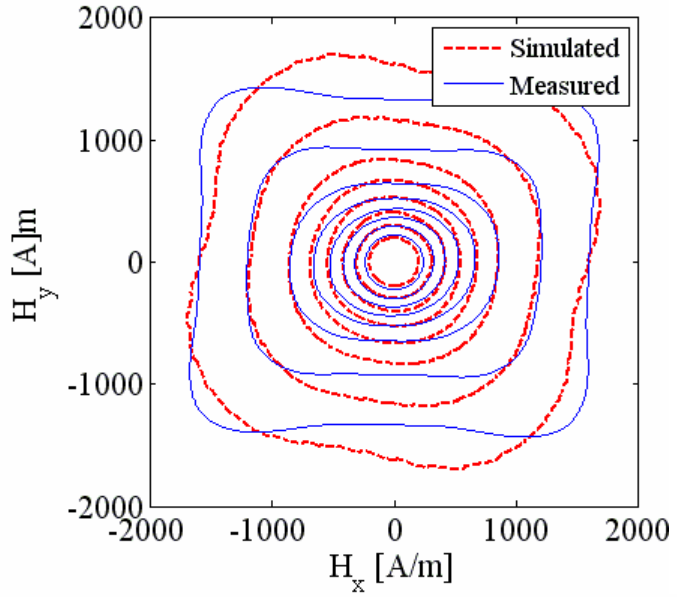

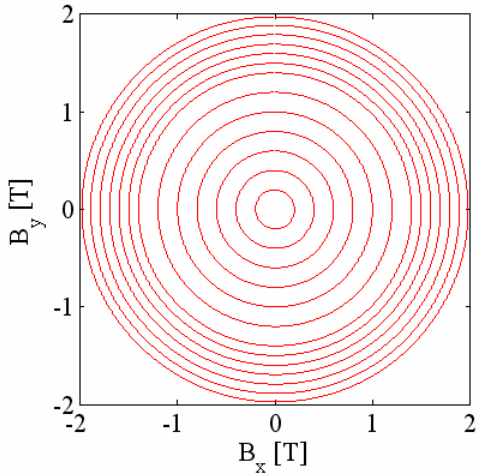

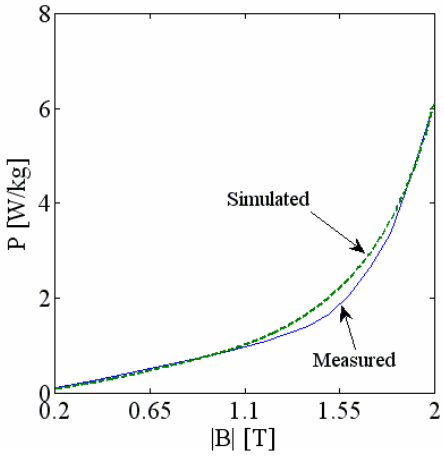

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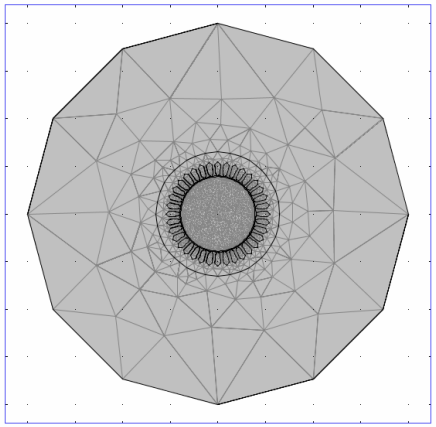
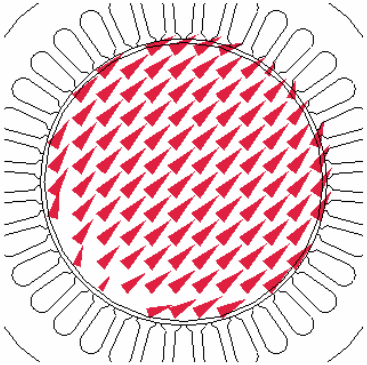
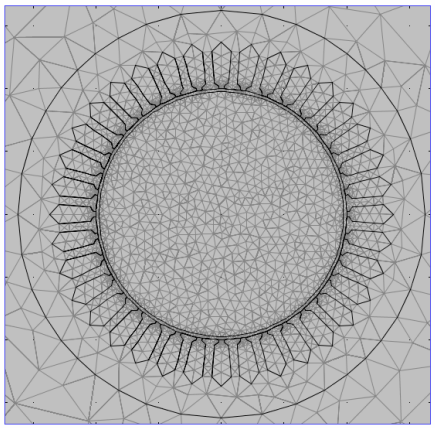
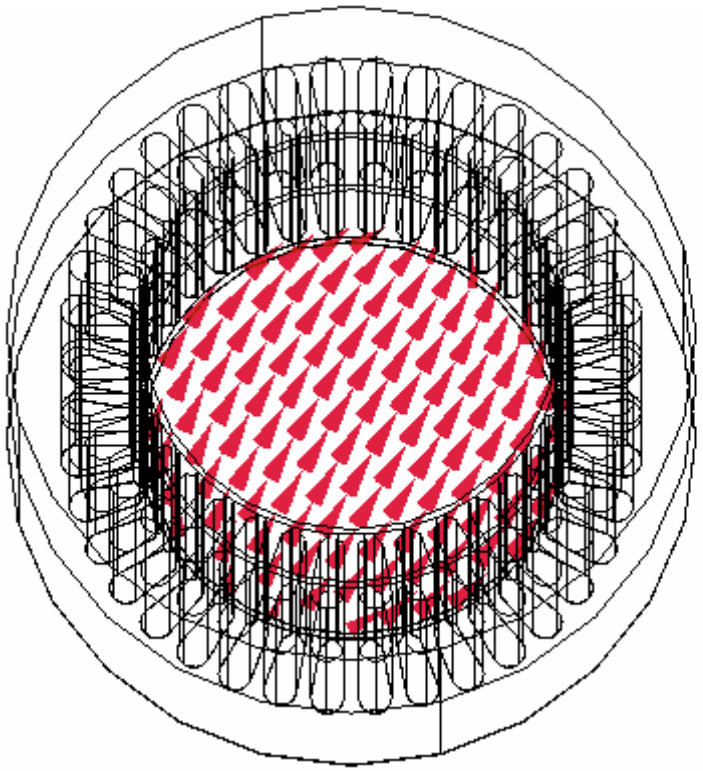
Application in FEM

- Reduced magnetic scalar potential, Φ
- Polarization technique
- Fixed point method
- Inverse vector Preisach model
- 3D Finite Element Method









48 640 prism elements
27 423 nodes
711 772 unknown for T_0
206 941 unknown for Φ

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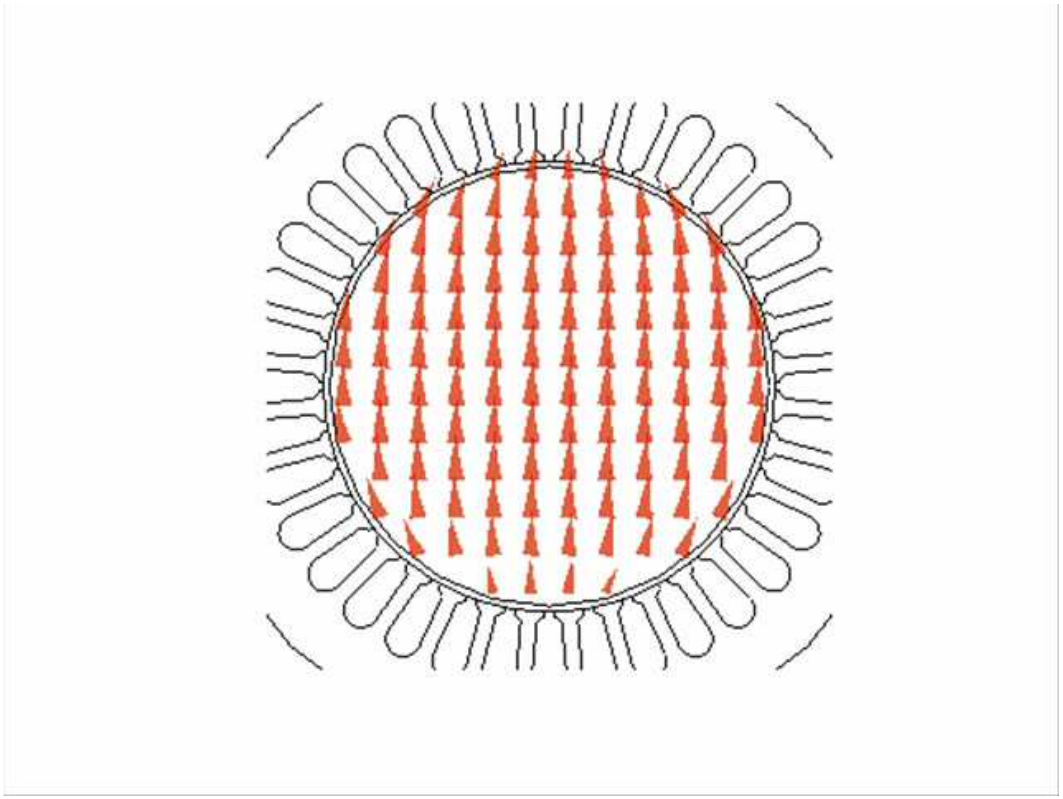
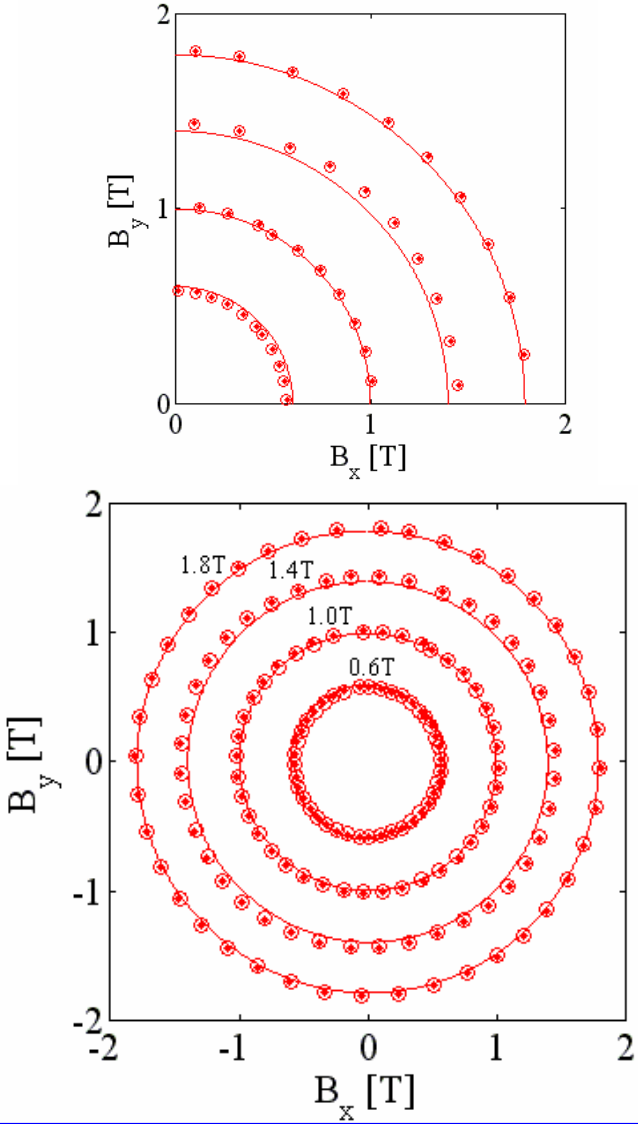
Application in FEM





The average *B* is equal to *B* in the center.

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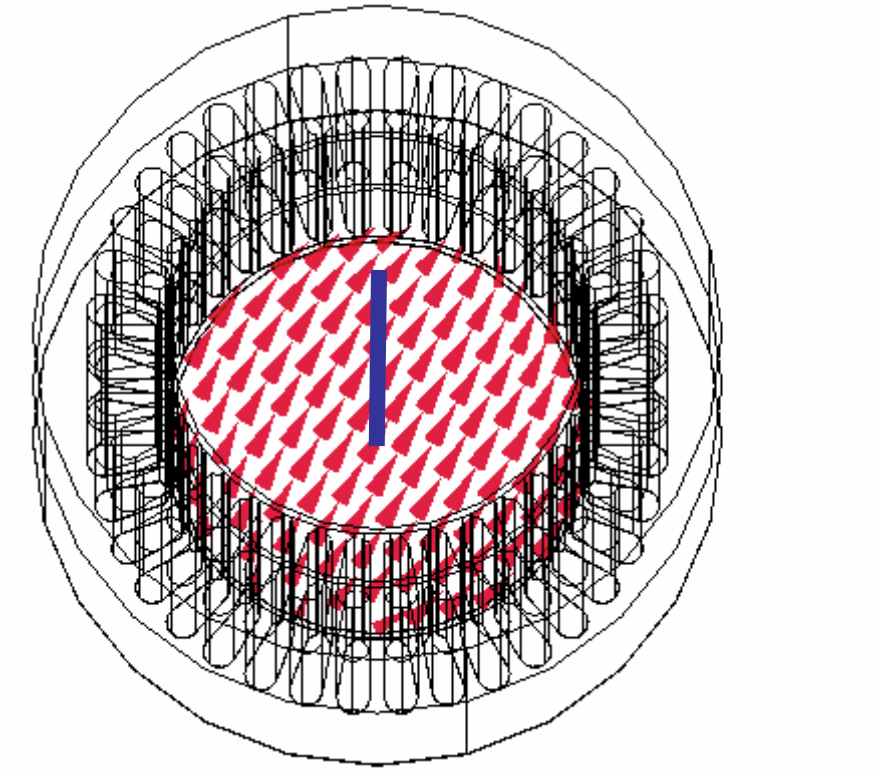

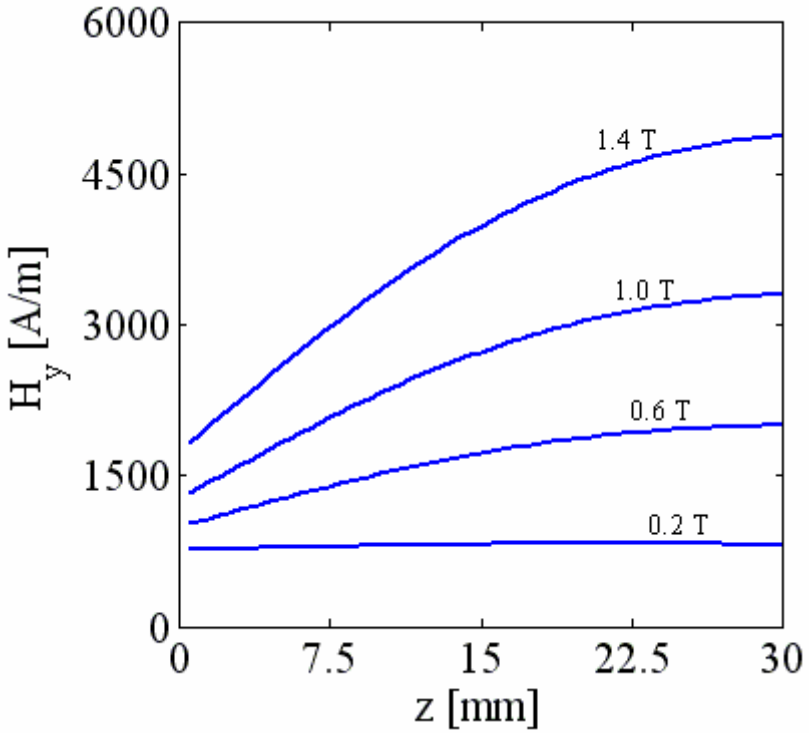

The linear extrapolation can be used to calculate ***H*** at the surface.

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Conclusions, Future Works

- **RRSST System**
  - Sensor system, calibration
  - Controlling of flux
  - Input data for the identification of vector Preisach model
- **Inverse vector Preisach model**
  - Identification technique
  - Frequency dependence
  - Minor loops
- **Insertion into 3D FEM**
  - Static magnetic field
  - Eddy current field
  - Other nonlinear problems and applications

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